Understanding the patterns and causes of variability in distribution, habitat use, abundance, survival and reproductive rates of three species of cetacean in the Alborán Sea, western Mediterranean

Ana Cañadas
ALNILAM Research and Conservation Ltd.
Cándamo 116
28240 Hoyo de Manzanares
Madrid, Spain
phone: +34 676481284 email: anacanadas@alnilam.com.es

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LONG-TERM GOALS

The question of how environmental variability affects populations of marine top predators is an important one because of their role within ecosystems and their potential to influence community structure and biodiversity (Heithaus *et al.* 2008). An understanding of the patterns of distribution and abundance and particularly the causes of that variation is critical to making informed assessments of the importance of anthropogenic activities to marine mammal populations.

This project will quantify changes in distribution, habitat use, abundance, survival and reproductive rates of three species of cetacean in the Alborán Sea (western Mediterranean) in relation to variation in the physical and biological environment and human activities, based on 18 years of data. The proposed study species, bottlenose dolphin (*Tursiops truncatus*), common dolphin (*Delphinus delphis*) and long-finned pilot whale (*Globicephala melas*) occupy different oceanographic niches off southern Spain. The Alborán Sea is a highly productive and distinct ecosystem that plays an important role in the oceanography of the Mediterranean basin, and has experienced marked changes in climatic and oceanographic conditions.

We will attempt to relate features of a species' biology to environmental change, particularly climate change, focusing on distribution, abundance and estimated reproductive and survival rates. The two last ones provide information on the mechanisms that cause distribution and abundance to change. Knowledge of these relationships will help us to predict the future impacts of environmental change in a way that studies of distribution and abundance alone cannot.

This project will do this using a two decade dataset on bottlenose and common dolphin and pilot whale in the Alborán Sea and the time series of environmental changes generated by IMEDEA (Mediterranean Institute for Advanced Studies) and by NOAA OceanWatch. Once established, these relationships will be used in conjunction with the simulations of environmental change generated by IMEDEA to predict the effects of further change on these species over the next 40 years. The existing dataset available for these species covers 18 years. Data on human activities (e.g. fisheries, maritime

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traffic) are also needed to explore how they interact with the environmental changes and with the species parameters changes.

OBJECTIVES

The primary goals of the research in this Grant are:

(1) Quantify relationships between measures of cetacean population ecology, dynamics and status (distribution, habitat use, abundance, survival and reproductive rates) and variation in the marine environment (physical and biological oceanography, prey distribution and relative abundance) for the three focal species over the last 18 years in the Alborán Sea;
(2) Test the hypothesis that environmental changes have had a greater effect on cetacean species that feed at lower trophic levels;
(3) Explore the relative contribution of environmental variation and anthropogenic activities on cetacean population changes;
(4) Quantify the effect of moving the Cabo de Gata TSS (the source of major noise pollution) on the distribution and abundance of the three focal species.
(5) Predict responses of the three focal species to future environmental change under a range of scenarios;
(6) Assess how well cetaceans can serve as indicators of environmental change in the marine environment and of "ocean health" generally.

APPROACH

To achieve the objectives of this project, the following steps will be taken:

(**Step 1**) existing data on the focal cetacean species (line transect sampling and photo-identification), human activities and environmental variables will be compiled and organized into appropriate strata at appropriate resolution and spatial and temporal scales;
(**Step 2**) some new data will be collected (summers 2010 and 2011) and, if sample sizes are large enough, they will be organized in the same way as the existing data to complete a 20 year dataset;
(**Step 3**) available information on changes in the marine environment over the last two decades (through collaboration with IEO and IMEDEA) will be organized to allow joint analysis with the cetacean and human activities data described above;
(**Step 4**) density surface modeling (spatial modeling) of line transect data will be used to relate changes in distribution, habitat use and abundance of the focal species to changes in the environment, including data on oceanography and human activities as explanatory covariates;
(**Step 5**) mark-recapture analysis of photo-identification data will be used to relate changes in survival and reproductive rate to changes in the environment again using oceanographic and human activities data as covariates;
(**Step 6**) models that are developed that relate changes in cetacean biological/ecological characteristics to changes in the environment will be combined with the output of environmental simulation models developed by IMEDEA to predict impacts up to 40 years into the future (through collaboration with IMEDEA).

WORK COMPLETED AND RESULTS

Step 1. Compilation and organization of existing data

Data on cetaceans

In 2012, existing survey data on the focal cetacean species from 1992 to 2010 and *in situ* data on human activities from 1998 to 2009 had been compiled and organized into effort and sightings files, both in the format for Distance sampling analysis (to estimate the detection function) and for spatial modeling. In 2013 new available data from 2010 and 2011 has been added and formated.

Data on environmental variables
These were obtained and organized already last year. This year, however, three new covariates were created in base to those: sea surface temperature with one month, two months, and three months lag in order to explore if the distribution of the animals has a delay with respect to the oceanographic covariates.

Data on fisheries
Fish catch data collection (IDAPES)
Fish catches data were collected through IDAPES (the Andalusian information system of marketing and fisheries production data dependent from the Directorate General of Fisheries and Aquaculture of the Junta de Andalucía). This system manages notes about first sale at fish markets, trap nets, frozen fishery products companies, marketing data from minor stores and wholesale markets, and non-commercial data as transport documents, registration documents concerning to bivalves, fish landing declarations and traceability data.

Monthly fish landing in kilograms of 283 commercial fish species landed in 13 different fishing ports villages of Andalucía were downloaded from 2000 to 2011, so that monthly variation of landings during this time period was possible to establish (see example of monthly sardine landing variation in fig 1).

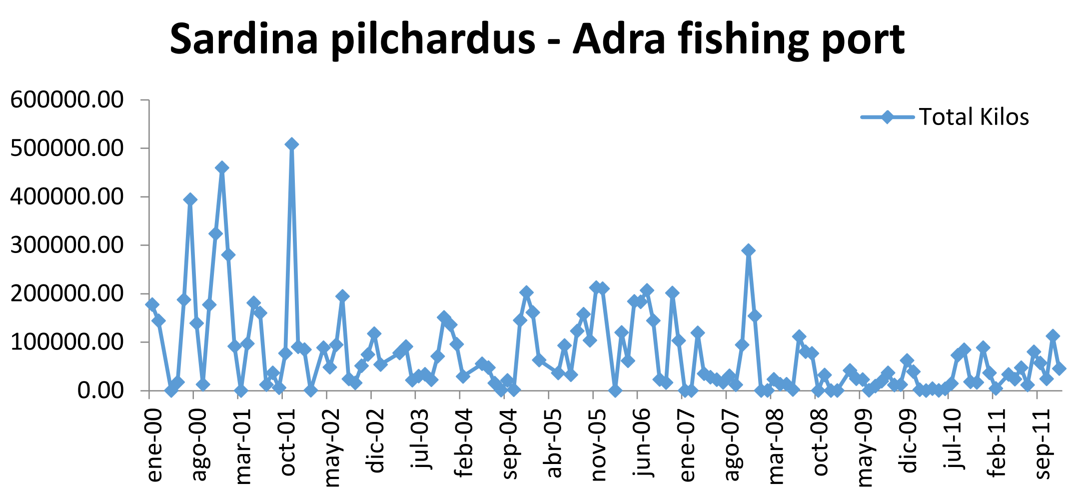
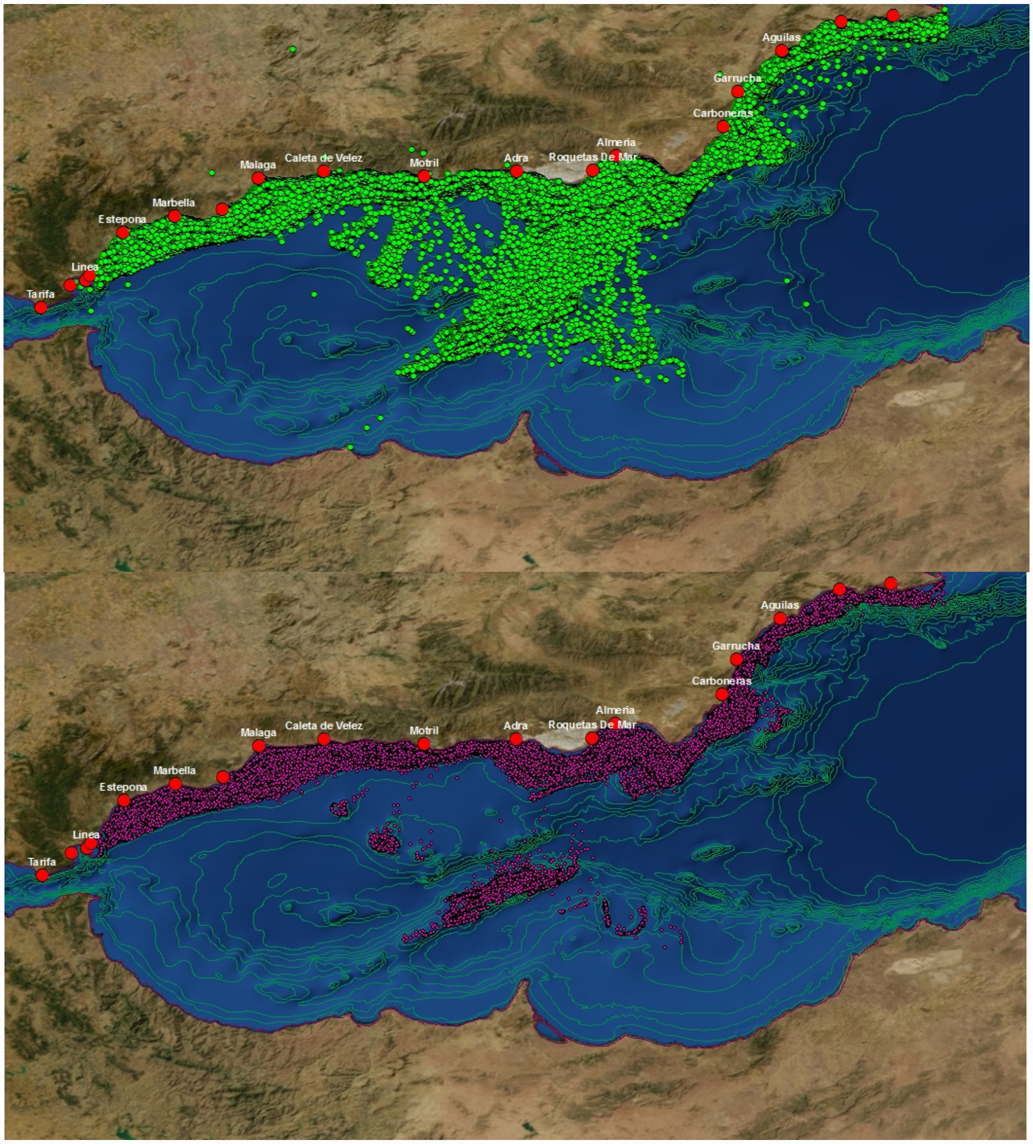


Figure 1. Monthly sardine landing variation in Kilos

Fishing activity data collection (VMS)
The Location System of Spanish Fishing Vessel (VMS) is an automated system that allows competent authorities to obtain satellite information on the positions of all fishing vessels over 12 meters at regular intervals of about 2 hours. The VMS tracks the movements of the ship and can provide information on their speed and direction. An official request on VMS data in Abloran Sea was sent to the General Secretariat of the Sea in May 2012. In April 2013, more than one year after the start of the

application steps, VMS data from 2005 to 2011 was delivered by post office to ALNILAM. Every file corresponding to each year included on average 500,000 different position (latitude-longitude) data that has been necessarily processed adequately using Excel and ArcGis softwares. Figure 2 shows all trawling fishing vessels positions in Alboran Sea during 2005.



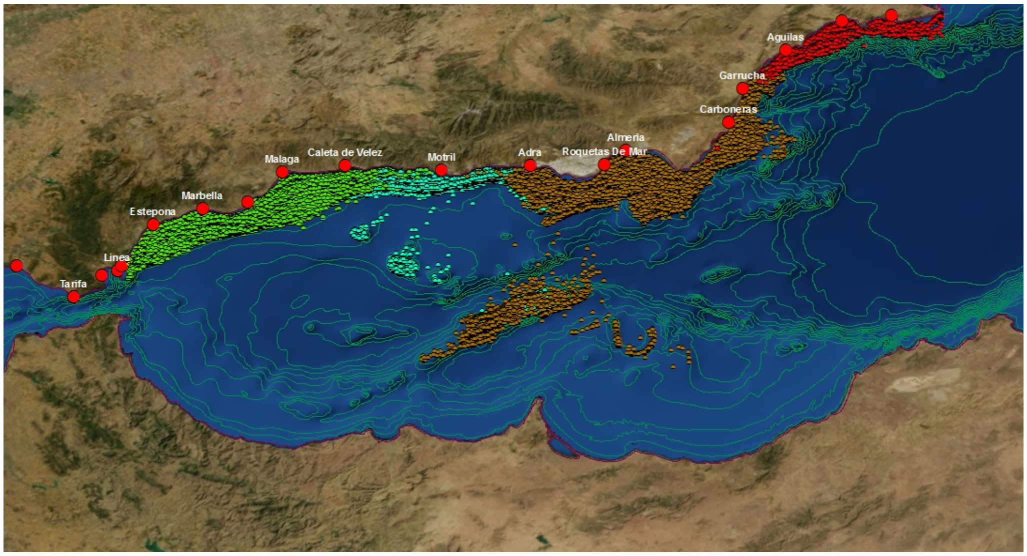


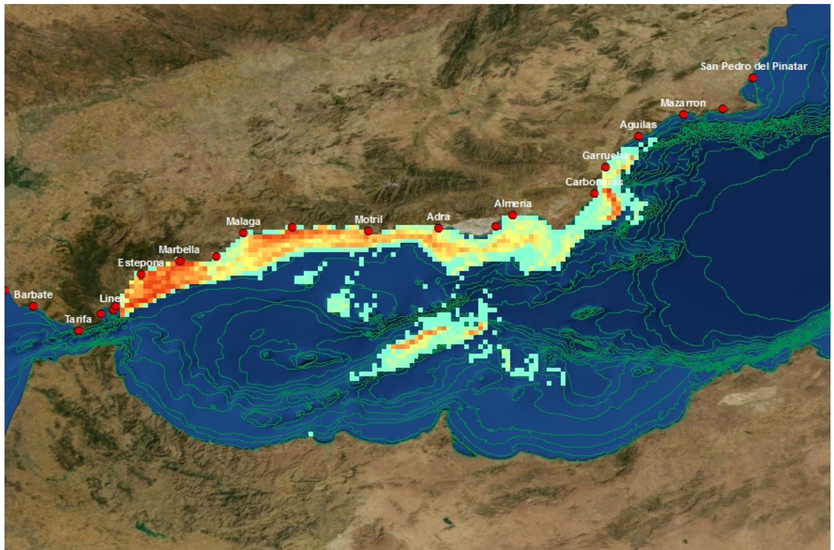
Figure 2. Upper map shows all trawling fishing activity points for 2005. Middle map shows the remaining points after the FILTERING PROCESS. Lower map shows points for each province.

<u>Cross process of fish landing and fishing activity data to get spatial correlated information</u>
Although VMS data contain information on real active fishing periods, this information is not reliable because depends on the fisherman honesty. Furthermore, there are specific characteristic for each fishing activity that must be taken into account in order to identify those points corresponding to the activity and those that must be removed. Fishing activity data coming from VMS was filtered to remove all points not indicating fishing activity. The filtering process for trawling fishing activity in 2005 was as follows:

TRAWLING FISHING FILTERING CRITERIA:

1. Delete points located less than 1 nautical mile from any fishing port
2. Only consider points with estimate speed (calculated as estimate distance between two consecutive points divided by time units) between 2 and 5 knots.
3. Trawling fishing activity in Alborán Sea is mainly carried out on a clear daily pattern so that trawler vessels go out early in the morning and come back to port to sell the fish just before get dark. Points recorded before 6:00AM and after 22:00 PM were deleted.

Once VMS data was filtered, spatial correlation processes were carried out in ArcGis to obtain the number of points in each 0.0333x0.0333 degrees cells. The number of points in each cell divided by the total number of points was considered as activity factor that will be used to transform fish landings into spatial information for each fishing port. The total amount of kilos for each target commercial species was calculated as the sum of kilos for each cell considering all ports. Figure 3 shows the spatial distribution of fish landings in kilos of 3 commercial fish species for trawling activity. Figure 4 shows the spatial distribution of fish landings in kilos of 3 commercial squid species for trawling activity.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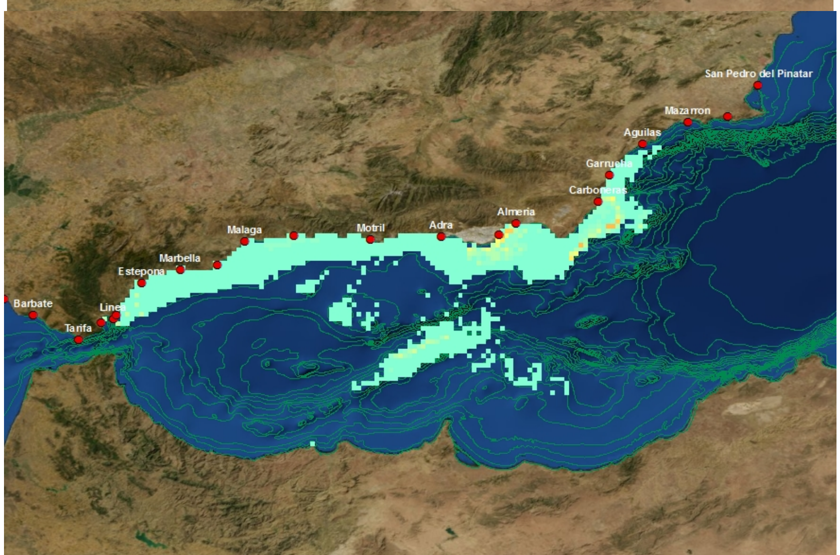
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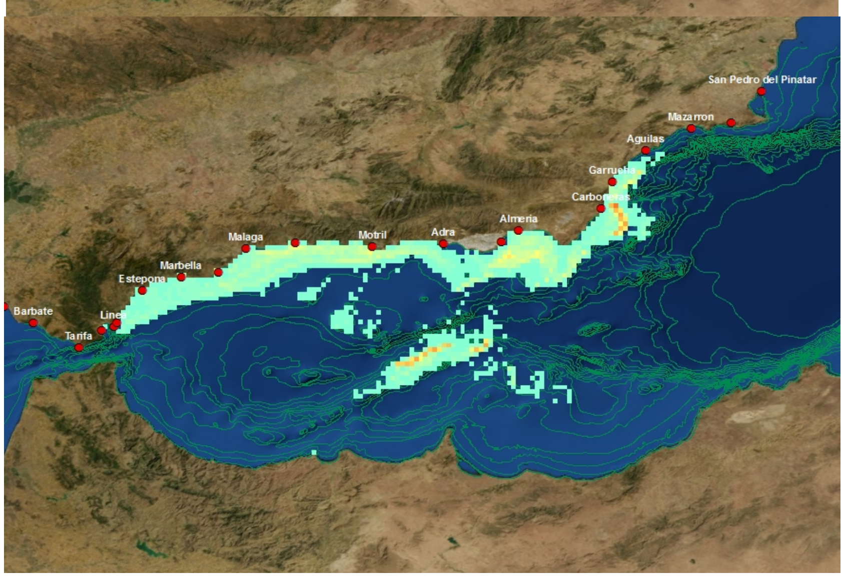
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Figure 3. Upper map shows whiting spatial distribution in 2005. Middle map shows sea bream spatial distribution in 2005. Lower map shows hake spatial distribution in 2005.

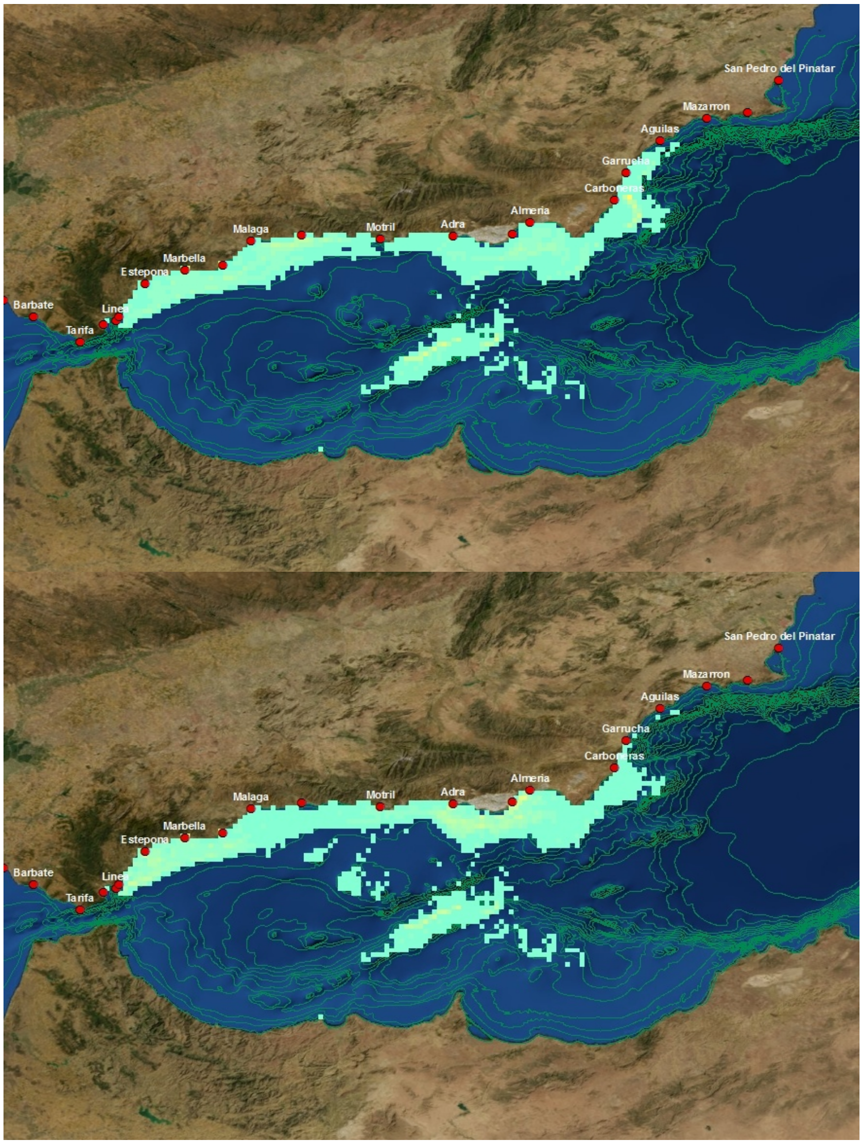

Figure 4. Upper map shows pota spatial distribution in 2005.. Lower map shows cuttlefish spatial distribution in 2005.

Step 2. New data collection

Data was collected through line-transect surveys at sea during summers of 2010 and 2011 (under GRANT N00014-09-1-0536), and added to the existing data, yielding a 20 year time series of data for the three focal cetacean species in the Alborán Sea. These surveys in 2010 and 2011 continued using the protocols developed over previous years (Cañadas & Hammond 2006; 2008). Photo-identification data for estimating survival and reproductive rates were collected during the same surveys and similarly added to existing data to create a 20 year dataset.

Step 3. Information on changes in the marine environment

Data on sea surface temperature climatology has been organized both for the whole year and for the summer months. The two plots below (Figures 5 and 6) show this climatology and the obvious trend of increase.

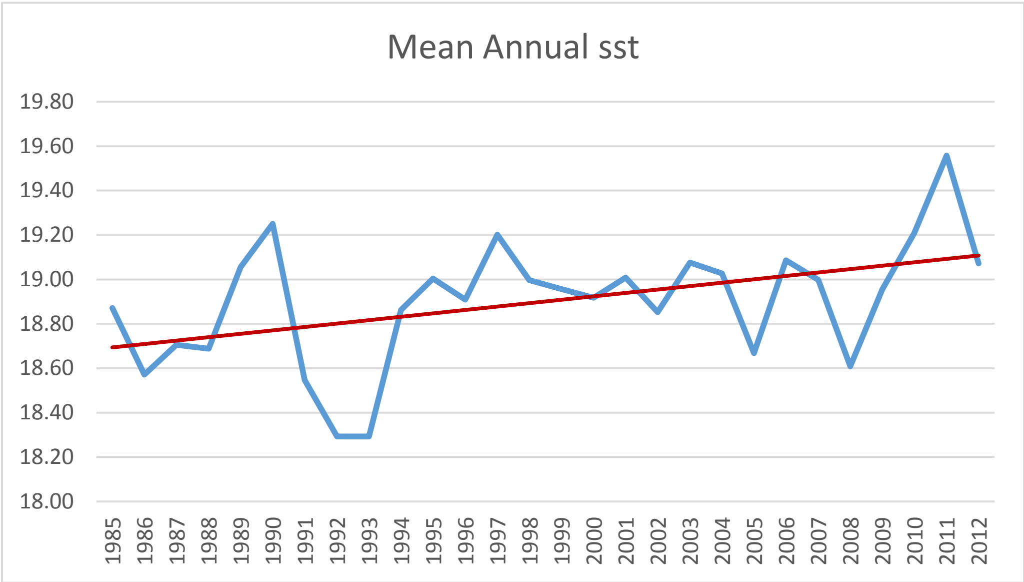

Figure 5. Climatology of annual sea surface temperature in the Alboran Sea

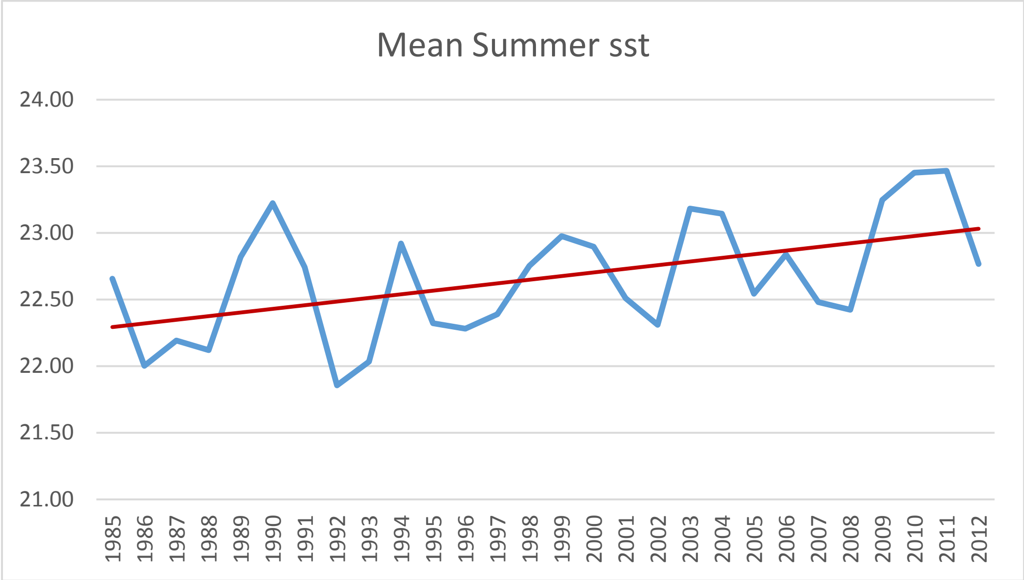

Figure 6. Climatology of annual summer sea surface temperature in the Alboran Sea

Following these plots, effort and sightings data has been arranged to group consecutive years with similar climatology (either above or below mean) in order to do the spatial modelling and investigate if this factor has an influence in the distribution of the animals.

Step 4. Density surface modelling

Density surface modelling of line transect data has been done for long-finned pilot whales with environmental and anthropogenic explanatory covariates looking at potential interannual variation. Only fisheries related covariates have not been tested yet as they are under processing at the moment. The most relevant anthropogenic covariate tested is the main lines of maritime traffic, in the form of distance to the main corridor, one to the marine traffic corridor before the displacement of the Traffic Teparation Schemme (TSS) off Cabo de Gata 20 nm to the south, and another one to the corridor after its displacement. The use of this covariate in the density surface modelling of pilot whales did not show any effect on their distribution. Probably these animals, being resident in the aera, are habituated to the high level of presence of large ships and their noise. However, the risk of collision exists as does the potentially negative effects of the noise produced by this intense marine traffic. Therefore, comparing the traffic lines before and after the displacepent of the TSS with the distribution of the animals, it is undeniable that ithas been a very positive measure as it avoids now the main denisty areas of pilot whales. Figures 7 to 10 show the traffic lines before and after the displacement of the TSS, together with the sightings of this species and the density prediction for both periods. It is very obvious that before 2006 the main traffic route pass right through the main density areas of long-finned pilot whales, while the new main route goes through a less dense area.Therefore it is expected that the potentially negative effect of the marine traffic on this species is to some extent mitigated with the TSS displacement.

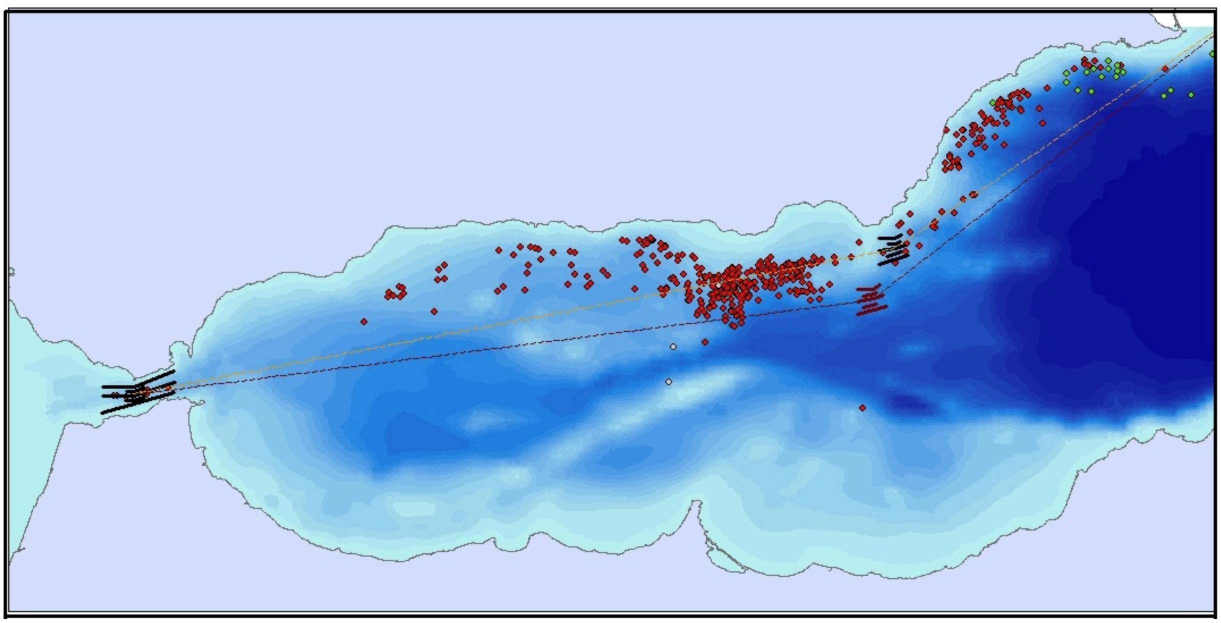

Figure 7. Main Maritime traffic routes (orange = before displacement of TSS in December 2006; black = after displacement of TSS) and long-finned pilot whales sightings for the period 1992-2006 (before displacement of TSS). Different colors of dots represent sightings from diffeent vessels.

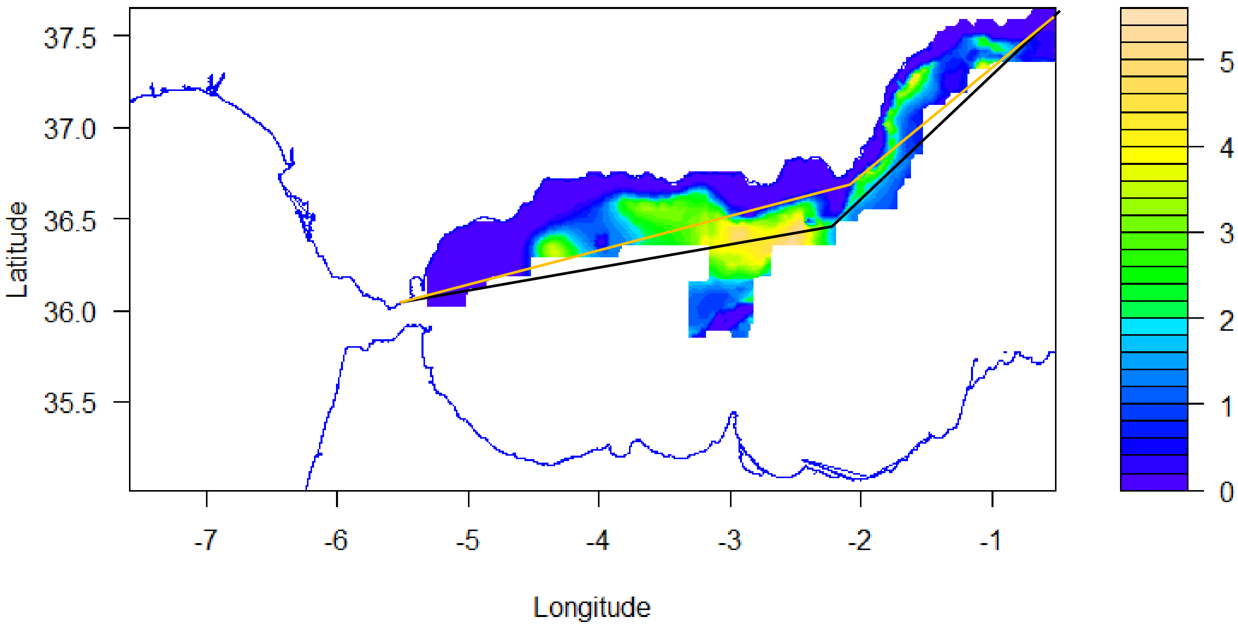

Figure 8. Main Maritime traffic routes (orange = before displacement of TSS in December 2006; black = after displacement of TSS) and long-finned pilot whales density prediction for the period 1992-2006 (before displacement of TSS).

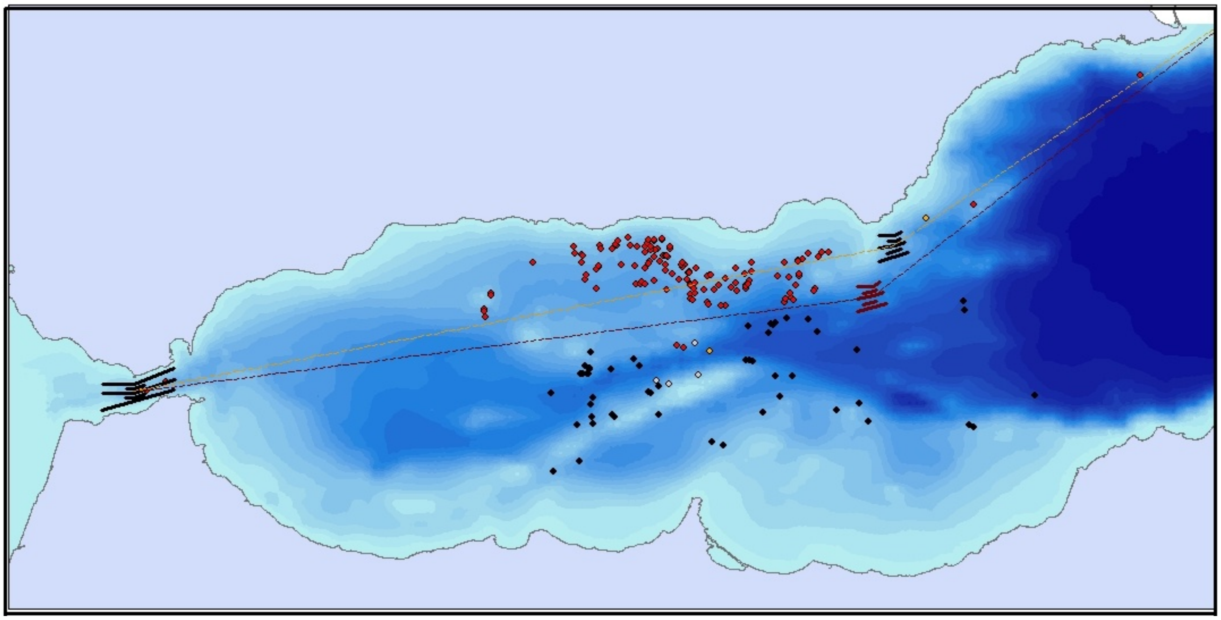

Figure 9. Main Maritime traffic routes (orange = before displacement of TSS in December 2006; black = after displacement of TSS) and long-finned pilot whales sightings for the period 2007-2010 (after displacement of TSS). Different colors of dots represent sightings from diffeent vessels.

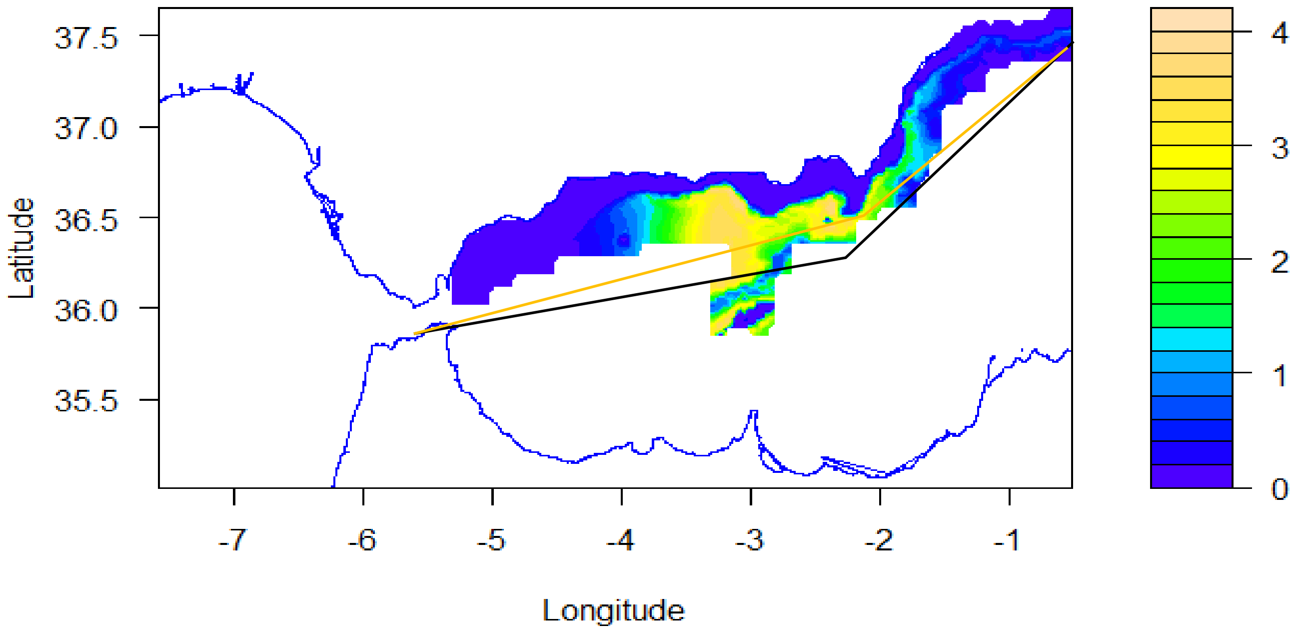

Figure 10. Main Maritime traffic routes (orange = before displacement of TSS in December 2006; black = after displacement of TSS) and long-finned pilot whales density prediction for the period 2007-2010 (after displacement of TSS).

In terms of oceanographic covariates, no effect at all could be observed of the sea surface temperature (SST), chlorophill concentration or primary productivity on the density of long-finned pilot whales. SST was tested in 5 different ways: (a) as actual SST on the day and position of each sighting; (b) the SST with a time lag of one, two or three months before the day of the sighting at its position; and (c) SST climatology for each year. None of these covariates explained any variability (less than 1%), neither considering the whole dataset, nor stratifying by areas or by groups of years. This makes sense considering that pilot whales are teutophagic, i.e. they feed on deep cephalopods, which do not depend on SST for their distribution, or at least in a direct way.

What seems to have had an effect on the population is the morbilivirus epizootia affecting long-finned pilot whales in the Strait of Gibraltar and the Alboran Sea in 2006-2007. There has been a reduction in abundance before and after the epizootia, although not significantly different when modelling the whole study area. Recalling the information on the existance of three clans of pilot whales in the area (see Step 5 below), it was stated, based on the occurrence of the strandings, that the epizootia affected mainly the clan of the Strait of Gibraltar, and in a much lesser extent those further to the East. In order to avoid confounding effects, only the area of Alboran, excluding the Strait of Gibraltar and the Gulf of Vera, was modeled before and after the epizootia. The abundance estimates were 2218 animals (CV=12.9%) from 1992 to 2005 and 1773 (CV=18.4%) from 2006 to 2011. It seems that this reduction is due mainly to a reduced group size rather than to a reduction of number of groups. From photo-identification work, the population of the Strait of Gibraltar has undergone a much more drastic decline, from around 350 individuals prior the epizootia to around 40 nowadays (R. de Stephanis, pers. comm).

Density surface modelling for the other two species will be carried out shortly.

Step 5. Mark-recapture analysis

Bottlenose dolphins

The catalogue has been analyzed already for social structure. A previous published study showed an increase of dolphins in the area of Almeria from 1997 to 2001 when a new decrease in numbers was observed until 2003. Field observations suggested a new increase in numbers between 2004 and 2006 with a subsequent decrease after that. The hypothesis of the new growth of the abundance of the species in the area was attributed to the income of an immigrant group between 2004 and 2006. The results of the photo-identification showed two periods of immigration with a population increase between 1997 and 2001 of 5% followed by a decrease of 5% until 2003. Between 2003 and 2006 an important immigration occurred seeing the population growing at a mean annual rate of 24.8%.
A constant apparent survival rate was estimated throughout the study period at 0.91 (SE:0.01, 95%C.I.:0.89-0.93). This low estimate has to be interpreted in the light of the large immigration followed by an emigration which is included in the apparent survival rate estimate. Different hypotheses were then tested, taking into account the effect of transience on the survival rate in the dataset, first to look at the effect of time on the capture probability, then on the survival rate. Certain periods of year were put together to look at the effect of the presence of immigrant groups of bottlenose dolphins observed during those years (between 1997 and 2000 then between 2004 and 2006). Finally the years of arrival (1997 and 2004) and departure of immigrants (2000 and 2006) and all other years in-between were also modeled because we were estimating the apparent survival rate which is estimated from a combination of both natural mortality and individuals leaving the studied area. The best model, based on its AICc value showed an effect of transience and changes in the apparent survival rates between the years of arrival and departure of immigrants and all other years in-between and the probability of capture changing over time.

Results showed important changes in the apparent survival rate between the different periods due to the fact that the emigration rate is taken into account in the apparent survival rate showing lower survival rates during the years of arrival and departure of immigrant groups. All the other years had a relatively high survival rate estimate for the species. Table 1 below shows these results.

Table 1. Results of the survival rates estimated from the best model with standard error (SE), 95% Confidence Interval (CI) and Coefficient of Variation (CV).

Periods	Survival rate	SE	95% CI	CV
all other years	0.935	0.030	0.844-0.975	0.032
Arrival of Immigrants 1997-1998 2004-2005	0.774	0.073	0.602-0.886	0.094
Departure of immigrants 2000-2001 2006-2007	0.832	0.060	0.682-0.920	0.072

The analysis of the photo-identification catalogue has shown that the social system was close to a system based in rapid disassociations and casual acquaintances.

The cluster diagram (Figure 11, cophenetic correlation coefficient = 0.81) indicates that most individuals were sighted with preferred companions, expending for than 19% of their time together. Defined by the Knot diagram at a level of 0.19 HWI.

The social structure shows the typical structure for the species with a fission-fusion societies, characterized by dynamic associations of varying strength and temporal stability (Well et al. 1987; Connor et al. 2000; Gero et al. 2005; Foley et al. 2010), but showing an intrapopulation stable structure over the time (Gowans et al. 2007).

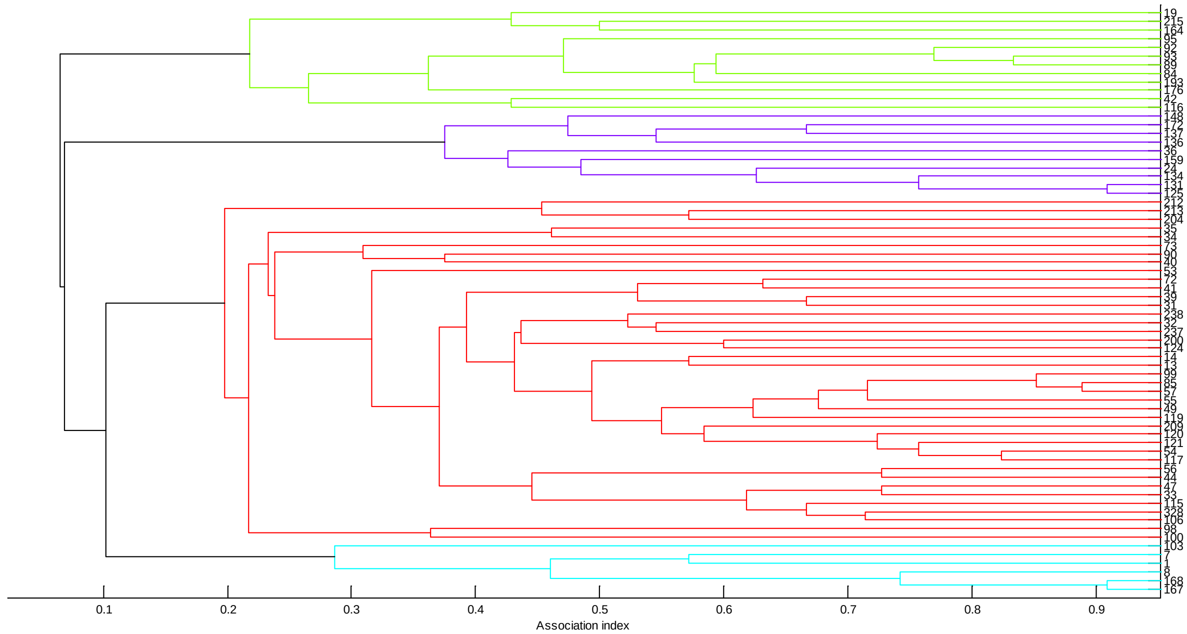

Figure 11. Cluster diagram for bottlenose dolphins

The social structure showed significant differences when we compared the three periods with a partial mantel test. This strongly confirms the presence of an immigrant group that interacted during 3 years with the local bottlenose dolphins of Almería.

The reproductive rate, in terms of proportion of groups with calves and the average number of calves in groups, has been investigated. The plot below (Figure 12) shows this for the summer months.

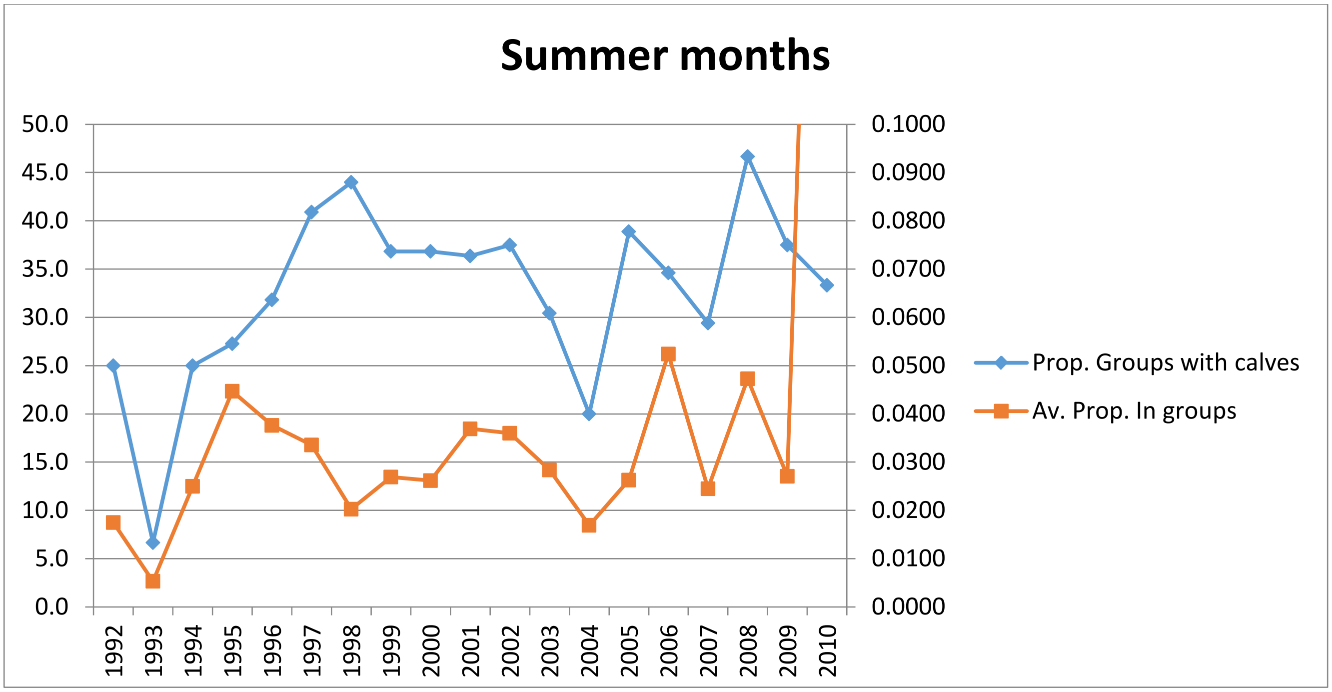

Figure 12. Reproductive rate of bottlenose dolphins during the summer months

Especially during the summer months, an increase of proportion of groups with calves was observed coinciding with the first inmigration event between 1997 and 2001. There is also an increase in 2005-2006 coinciding with the second inmigration event (according to field observations, this second event started in November 2004, after the main reproductive season during summer). No relationship has been found so far with environmental factors, but more analysis will be done shortly, especially considering a one year lag between environmental factors and observations of calves.

Long-finned pilot whales

The photo-identification catalogue has been completed until 2009 and part of 2010. An analysis was done to determine whether survival rates differ between clusters of the Mediterranean Spanish waters population, as several clusters were identified, and how the Western Mediterranean epizootic of morvillivirus in 2006-2007 influenced survival rates.

A half weight association index was used to define clusters of individuals that associate with each other more frequently than with others (Figure 13). A Cormack-Jolly-Seber survival rate model was then implemented. Apparent survival rate estimates varied from 0.82 to 0.99 over 11 clusters for the 1992-2009 period.

When the effect of the Morbillivirus outbreak was modeled, three clusters with distinctly lower survival rates (0.821, 0.891 and 0.918) from previous models, presented lower estimates after the outbreak (survival rate dropped from 0.919 to 0.547), supporting a negative influence of the epizootic or other unknown and/or additive factors on certain clusters. To our knowledge, this is the first published study evaluating the effect of a Morbillivirus epizootic on a cetacean population. The results showed within population differences, as not all clusters were affected by the outbreak in the same way.

All this analysis has yielded a publication now been submitted to Aquatic Conservation, with the master student performing this analysis as the leading author. The manuscript is added as Annex I.

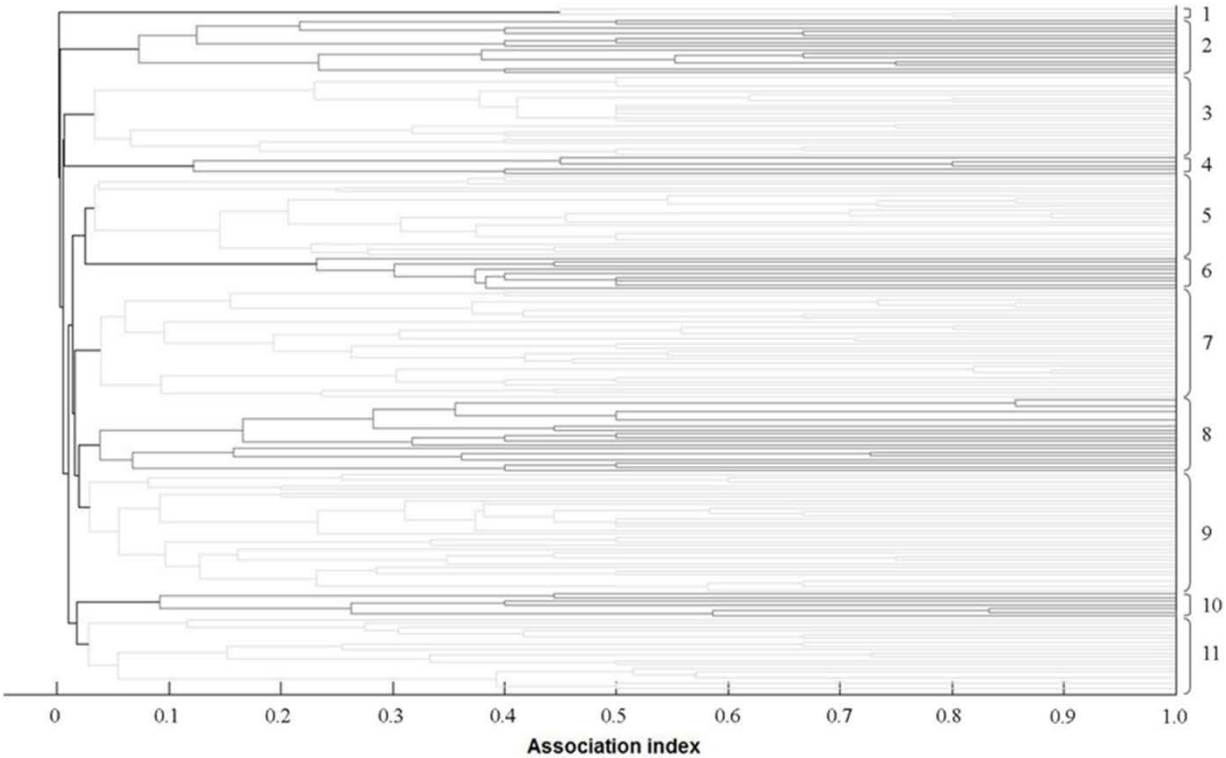

Figure 13. Cluster diagram for long-finned pilot whales

The reproductive rate, in terms of proportion of groups with calves and the average number of calves in groups, has been investigated. The plot below (Figure 14) shows this for the summer months. There is a clear decrease in the proportion of groups with calves from 1992 until 1999 but then it starts recovering again. In terms of the proportion of calves in the groups, tehre seems to be strong interannual variations. All these variations will be investigated in relationship with the environmental changes.

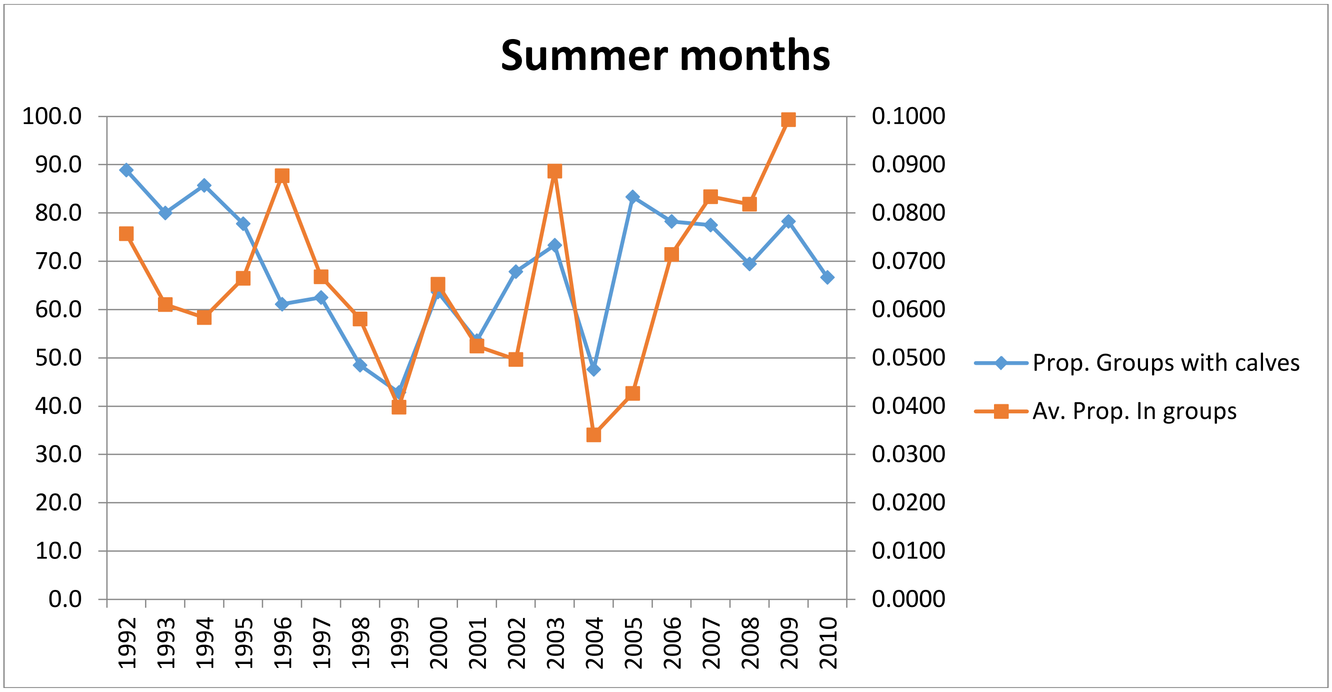

Figure 14. Reproductive rate of long-finned pilot whales during the summer months

An important issue to consider is that, apparently, three distinct clans of pilot whales exist in the Alboran Sea. One would cover mainly the Strait of Gibraltar but with some incursions in the westernmost end of the Alboran Sea; a second one would coevr the central part of the Alboran Sea from Almeria to Granada; and the third one would cover the aera of the Gulf of Vera with some incursion down in Almeria. The last two groups seem to have more sporadic mixing than with the first one. This information comes, on one hand, from the photo-id catalogue (several recaptures between Almería-Granada and Gulf of Vera, and no recaptures between those and the AStrait of Gibraltar), and on the other hand from satellite tagging of several pilot whales in collaboration with CIRCE (R. de Stephanis, pers. comm). Figure 15 shows an example of several pilot whales tagged with satellite taggs and their cleaned and processed positions.

Ideally, all sightings should be assigned to one of these clans, and then obtain survival rates and habitat modelling for them separatelly to avoid confounding effects. That is beng attempted with the spatial modelling by restricting some analysis to the Gulf of Vera and others to the aera of Almeria, not considering the area of the Strait of Gibraltar and adjacent areas. A real assignment of groups to each clan might be much more difficult given the partial overlapping of the areas at their edges.

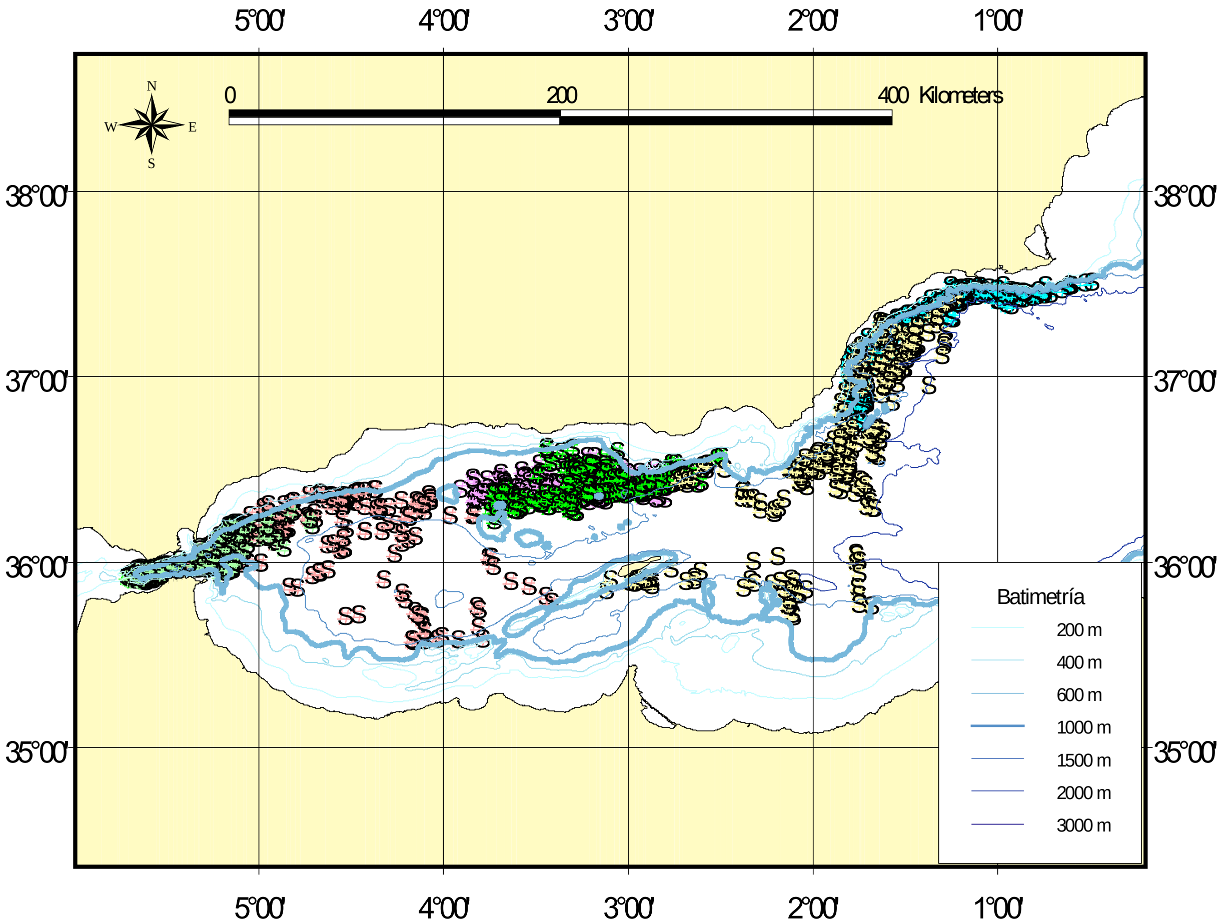

Figure 15. Satellite tracking of long-finned pilot whales in the Alboran Sea between December 2010 and September 2011. Each color is a different individual. (R. de Stephanis, pers. comm)

Common dolphins

A total of 18,321 photographs are being processed. Of these, 14,077 images of fins have been obtained from 1991 to 2011. The distribution of fins processed by year up to now are:

Year	**Fins obtained**
1991	12
1992	633
1993	430
1994	731
1995	1,017
1996	248
1997	
1998	4
1999	1,748
2000	905
2001	
2002	

2003	2,185
2004	1,874
2005	1,386
2006	
2007	1,744
2008	
2009	1,090
2010	28
2011	42
TOTAL	**14,077**

An initial exploration of the catalogue has been done for year 2004, resulting in 278 individuals, of which 43 were positevely females with calves. It was estimated that, on average, only 10% of the individuals in a group could be photo-identified, due to the difficulties of photographing all the animals in very large groups (of many dozens mostly and several hundreds many times), and the small percentage of marked animals. Only one animal was recaptured within those 278 individuals identified, pointing to the large population size of common dolphins in the area.
The analysis of more years will start in November.

The reproductive rate, in terms of proportion of groups with calves and the average number of calves in groups, has been investigated. The plot below (Figure 16) show this for the summer months.

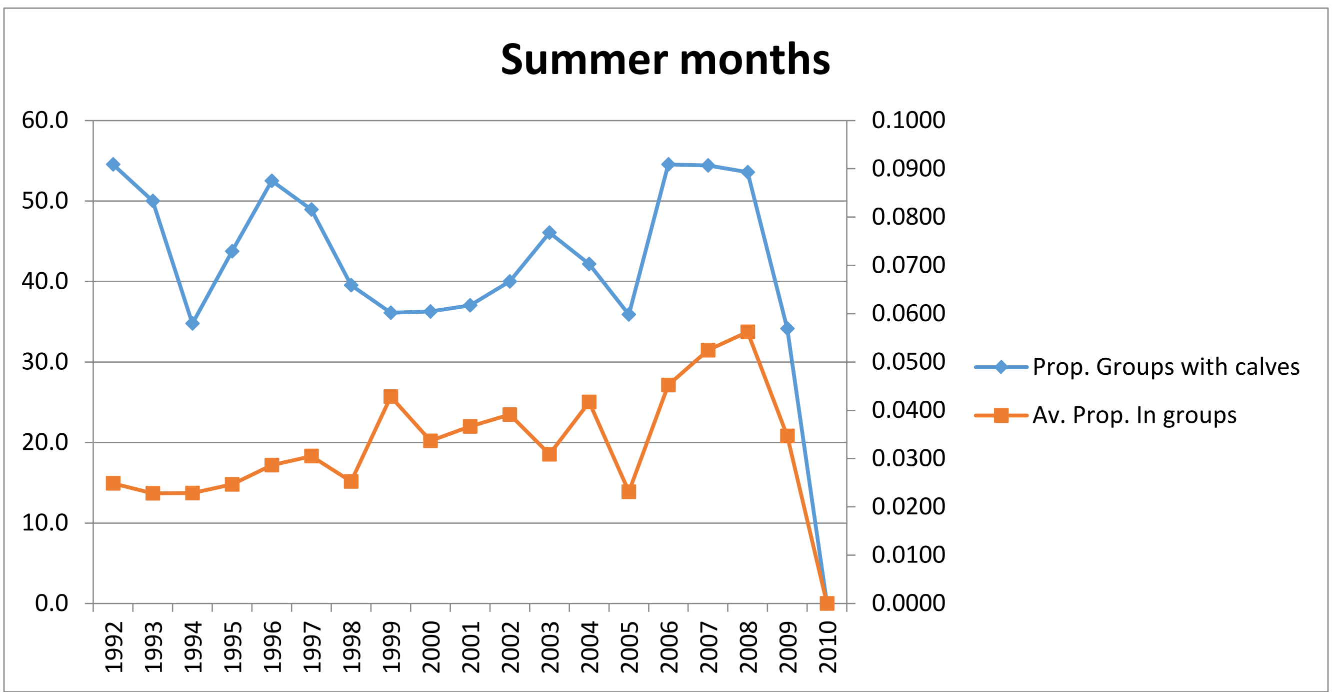

Figure 16. Reproductive rate of common dolphins during the summer months

The drop in 2010 is meaningless since only 4 sightings were recorded that year where the presence of calves could be assessed, so sample size for 2010 is too small (for the other years it varies between 24 and 111 sightings with assessment of presence of calves). No relationship has been found so far with

environmental factors, but more analysis will be done shortly, especially considering a one year lag between environmental factors and observations of calves, although there doesn't seem to be a clear pattern except a general increase in the proportion fo calves in the groupsover the years (not observed for the proportion of groups with calves).

Step 6. Predictions into the future.
This step will be carried out during FY 2013-2014.

RESULTS

See section above (Work completed and Results). All work is in progress.

Given that the project was scheduled to start in April 2011, but it actually started in September 2011 due to delays in the review and decision making process by ONR, a request for 6 months to one year no-cost extension was submitted, in order to finish all the analysis and reports. Therefore, a one year extension has been provided with new deadline for finishing the project on 30th September 2014.

RELATED PROJECTS

None

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PUBLICATIONS

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